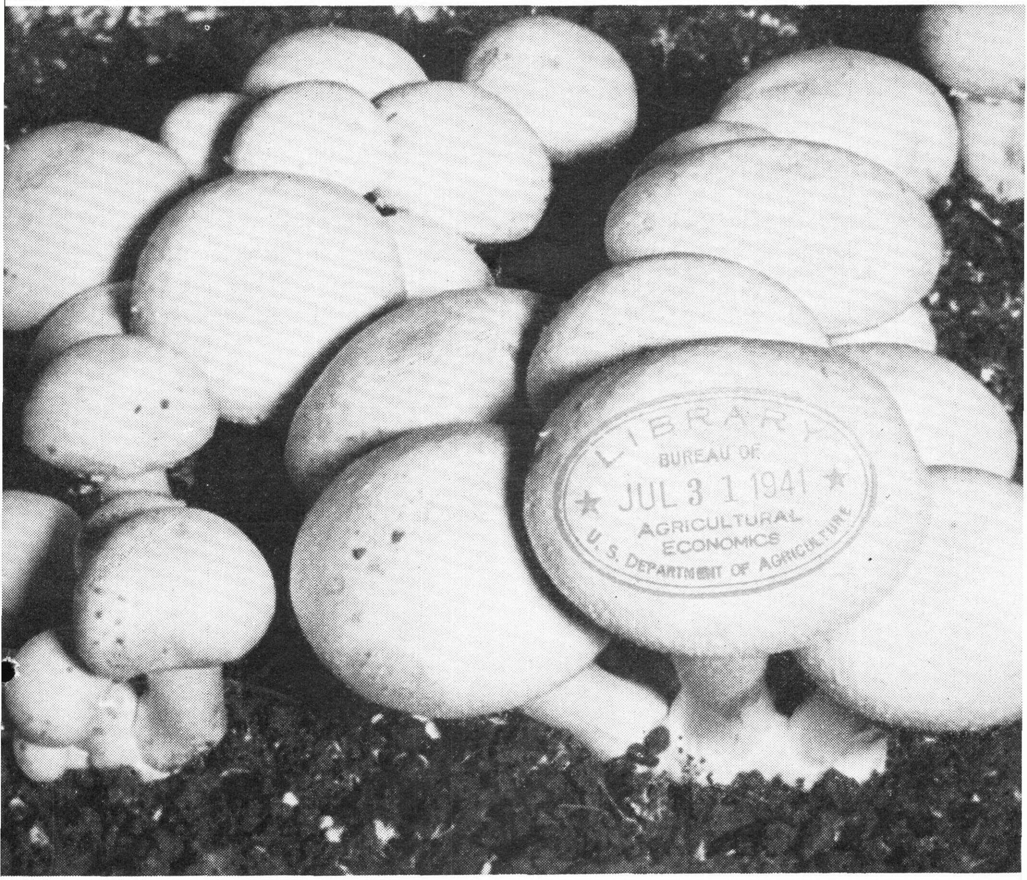
Mushroom Growing

IN THE UNITED STATES



FARMERS' BULLETIN NO. 1875

U.S. DEPARTMENT OF AGRICULTURE

MUSHROOM production has substantially increased during the past decade and there has been a lowering of prices and a wider distribution and consumption, particularly of mushrooms in small cans and in canned soup. Many people have added mushrooms to their diet who previously were hardly aware that mushrooms existed. This has given rise to a widespread belief that mushroom growing is a new industry offering unusual opportunities for profit. As a matter of fact, for the newcomer in the field opportunity has decreased from year to year with the lowering of prices. Under present-day highly competitive conditions experienced commercial growers have been able to show a profit only through constant improvement in cultural practice.

This bulletin was written in order to answer inquiries from inexperienced persons contemplating the commercial growing of mushrooms and is written in considerable detail so as to furnish a true picture of the complexity of commercial mushroom culture. Some new material is included, which may be of value to established growers. The bulletin is a revision of and supersedes Circular 251 and Farmers' Bulletin 1587.

Washington, D. C. Issued June 1941

For sale by the Superintendent of Documents, Washington, D. C. - - - - Price 10 cents

MUSHROOM GROWING IN THE UNITED STATES

By Edmund B. Lambert, *pathologist, Division of Mycology and Disease Survey, Bureau of Plant Industry*

Contents

INTRODUCTION

Mushroom culture has made rapid strides in the United States during the past quarter century, both in point of total production and of refinements in cultural practice. The canning of mushrooms has increased in recent years until at the present time mushroom soup is one of the best sellers of the nationally advertised brands. There are several hundred commercial growers; their total annual production is about 35,000,000 pounds. Centers of production have sprung up near most of the large cities where the climate is suitable (fig. 1).

This development, however, should not be interpreted as indicating that mushroom growing is a profitable venture for the inexperienced. All phases of the industry have become highly competitive, and the low prices prevailing in most markets make it necessary to obtain an average yield of nearly 1½ pounds per square foot of bed space in order to cover expenses. To obtain yields of this amount consistently

requires a thorough knowledge of the complex cultural practice and skill in following out this practice which can be developed only through long experience.

Under these circumstances a newcomer in the field will almost surely be disappointed if he expects to make profits during the years he is learning to grow mushrooms. On the other hand there is considerable satisfaction to be had from growing mushrooms for home

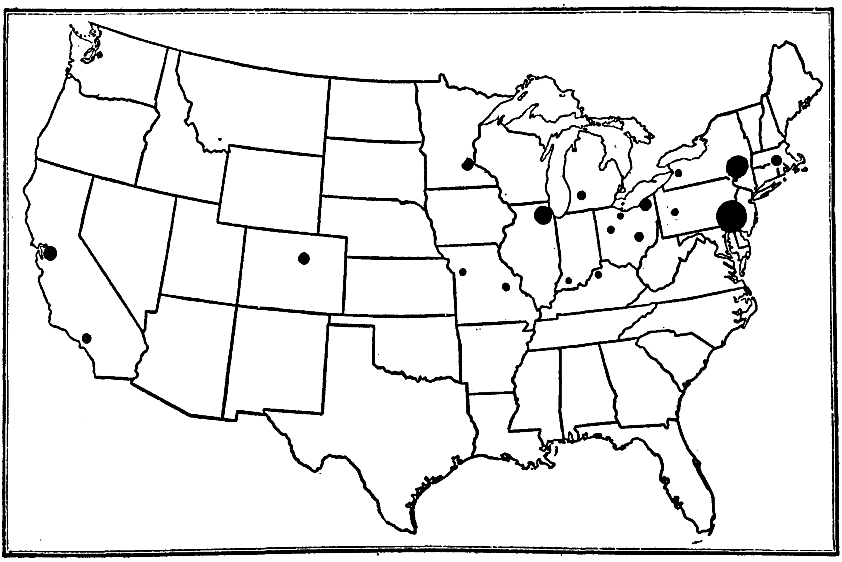


FIGURE 1.—The approximate distribution of the mushroom industry in the United States, shown by dots.

consumption or on a small scale for a local market. As mushrooms do not need light for normal development, they can be grown in a basement room or shed where it would be impossible to grow green plants. This also permits growing them during the winter months. For the amateur garden enthusiast mushroom culture offers a fascinating winter hobby with a reward for family and friends and plenty of new problems constantly cropping up to stimulate the interest.

NATURE OF THE MUSHROOM

The cultivated mushroom, technically known as *Agaricus campestris* L., belongs to a group of plants classed as fungi. In appearance and structure mushrooms are very different from ordinary plants. The parts of a mushroom (fig. 2) may be described as follows: The cap or pileus, the expanded umbrellalike portion at the top; the stem or stripe, bearing the cap; the gills, the platelike folds on the lower surface of the cap on which the spores are borne; the spores, which are minute, microscopic bodies, similar in function to seeds; the veil, a membranelike structure, which in the young condition covers the gills and reaches from the margin of the cap to the stem; the mycelium, which corresponds to the roots of higher plants, being the white, more

or less cottony and threadlike to cordlike strands which run through the beds and from which the mushrooms develop.

Mushrooms are more homogeneous in texture than most of the green plants. All of the plant that appears above ground is edible, as the flesh of the stem is nearly as soft as that of the cap and there is no protective covering, such as the bark on the stems of higher plants or the waxy bloom on fruit and leaves.

Perhaps the most fundamental difference between mushrooms and green plants lies in the fact that green plants can manufacture their own carbohydrate food, whereas mushrooms cannot. For this reason the mycelium of the mushroom must grow in organic material

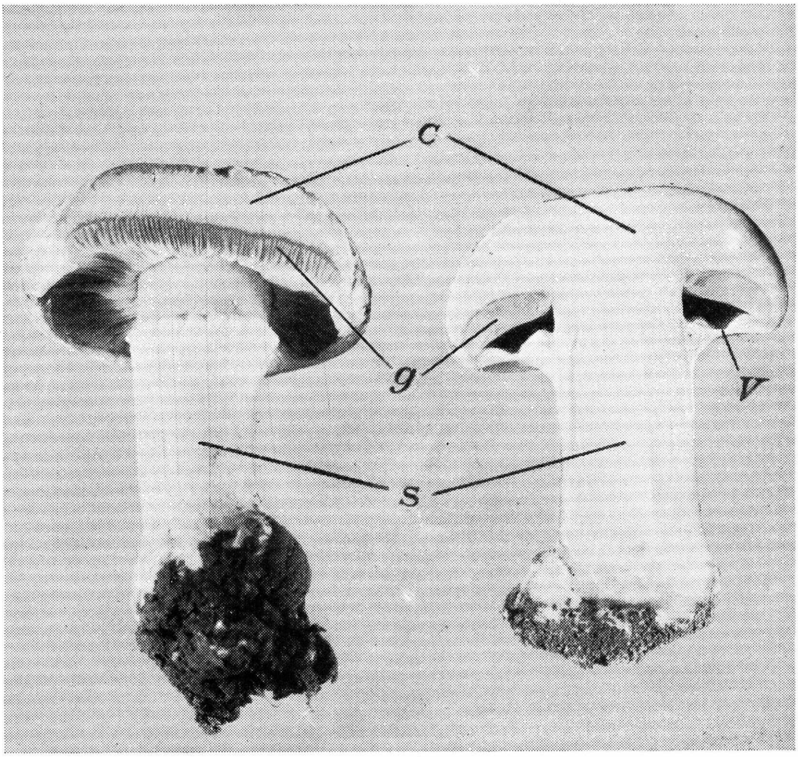


FIGURE 2.—Mushroom structure: *C*, Cap; *G*, gills; *S*, stem; *V*, veil.

containing carbohydrates, such as sugar, starch, cellulose, or lignin, in addition to the mineral and nitrogen fertilizer required by green plants.

The mushroom also differs from most green plants in having a full root system before it appears above ground. It is a rather common experience in the fall to find full-grown wild mushrooms after a rain in a locality where there was no sign of them 2 or 3 days before. This rapid growth is made possible by the fact that the mycelium of the mushroom spreads in the soil and absorbs a reserve supply of food during the summer months but does not produce mushrooms until stimulated by the cool nights and rains in September and October.

SPAWN AND MUSHROOM VARIETIES

In nature mushrooms are propagated by means of their spores, which serve the same purpose as seeds but differ from them in that the spores are microscopic in size and do not contain an organized embryo. When mushrooms are cultivated artificially the spores are germinated and developed into a propagative material called spawn, which is used for planting the beds. The spawn is grown on sterilized solid material in bottles of about a quart capacity (fig. 3). In making spawn the

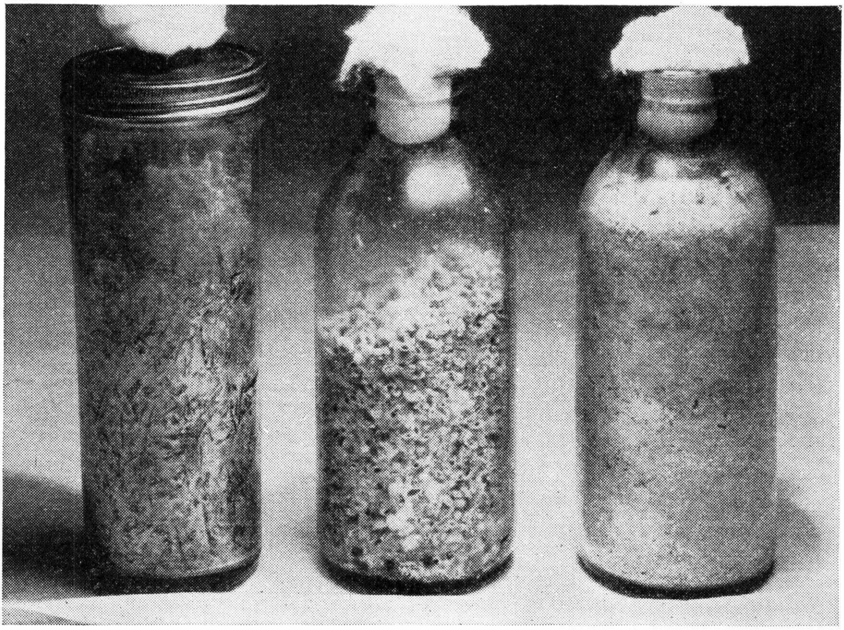


FIGURE 3.—Mushroom spawn in culture bottles, growing on different types of material.

mushroom spores must be gathered, germinated, and grown in the absence of all contaminating molds. This is a highly technical process, requiring laboratory apparatus and a knowledge of pure-culture methods. For this reason the manufacturing of mushroom spawn has been developed chiefly by a comparatively small number of growers who make a specialty of growing spawn and selling it to other growers. No attempt will be made in this bulletin to go into the details of the methods of spawn making.

As a rule commercial mushroom growers find it advisable to avoid the difficulties and uncertainties of making spawn by buying their spawn from a specialist.

A list of spawn manufacturers may be obtained by writing to the Bureau of Plant Industry, United States Department of Agriculture, Washington, D. C. The Department does not make spawn for distribution but will be glad to give more detailed information on making spawn to anyone interested.

Most of the cultivated mushrooms grown in the United States are of the white variety variously known under different trade names as

"Snow White," "White King," "White Queen," etc. This variety is very prolific and is preferred by nearly all markets because of its attractive clean white appearance. The amateur grower who is producing mushrooms for home consumption should by all means grow this variety, but he would also do well to try a small bed of brown mushrooms, which have a distinctly different flavor and will frequently produce a crop under more adverse conditions than the white.

WHERE MUSHROOMS MAY BE GROWN

As mushrooms are usually grown indoors their culture is to a certain extent independent of the weather. The principal requirements are that a pasteurizing temperature (130°–145° F.) be maintained in the growing room for several days during sweating out and a temperature of less than 60° F. during the growing period, with a moderately high moisture content in the air (relative humidity of 70 to 85 percent). The climate in most of the Southern States is unsuited for mushroom growing, because it is impossible to maintain a low enough temperature except during 1 or 2 months in the winter without the aid of expensive artificial refrigeration. Likewise, it is more difficult to grow mushrooms in arid regions than in humid regions, because of the tendency toward excessive drying out of the mushroom beds during both the sweating-out period and the growing period.

SPECIAL MUSHROOM HOUSES

In the industry as a whole, the specially constructed house has found most favor, and at least three-fourths of the mushroom crop in the United States is grown in these houses (fig. 4). The principal

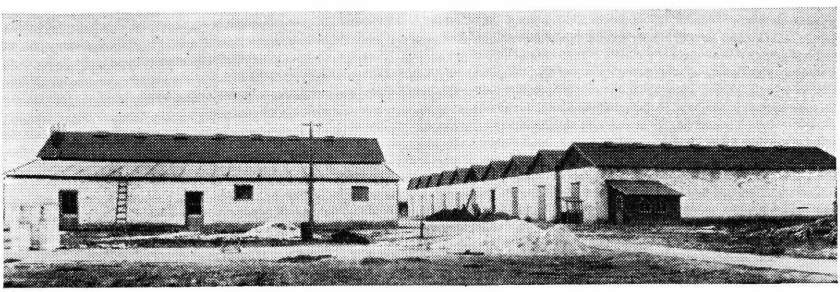


FIGURE 4.—Standard mushroom houses near Los Angeles, Calif.

advantages of such a house are: It can be suitably located with relation to railroad facilities, markets, and manure supply; ventilation, temperature, and humidity can be easily controlled, the air temperature in the house being raised during final fermentation and the moisture and temperature controlled during the spawn run and the bearing period; and separate houses may be handled as units during fumigation, so as to prevent the migration of harmful fungi and insects from old beds to new.

Also mushroom houses are designed to simplify and facilitate such operations as filling the beds, spawning, picking, emptying the beds, disinfecting, fermentation in the house, heating soil, heating, and

ventilating. Experience has shown that a house constructed as described in the following paragraphs meets these requirements (fig. 5).

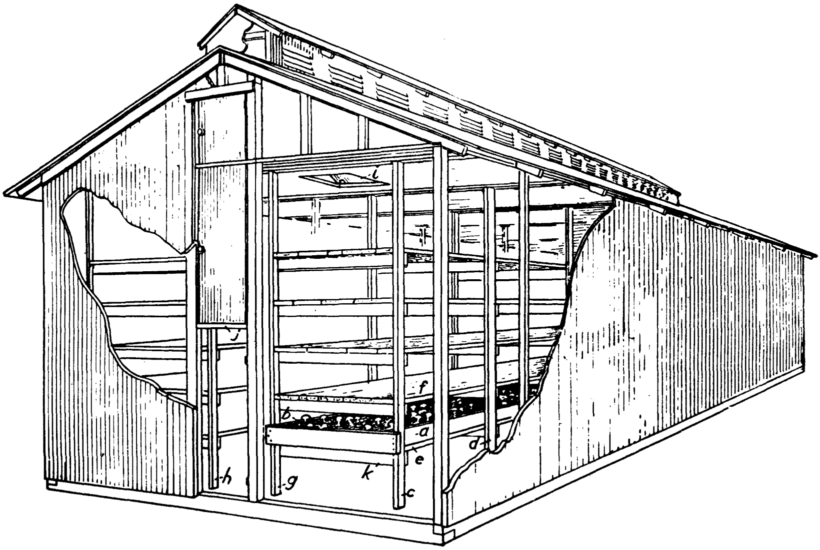


FIGURE 5.—Mushroom-house construction: *a* and *b*, Side boards; *c*, *d*, *g*, and *h*, uprights; *e* and *f*, bottom boards; *i*, hinged vent in ceiling; *j*, elevated runway.

CONSTRUCTION OF THE BEDS

In a standard house there are 2 tiers of beds, 5 to 8 beds high. A space of 6 inches to 1 foot is left beneath the bottom bed to insure a good "heat" (p. 16) during the fermentation of the compost in the bed. A space of 2 feet is allowed between the bottom boards of the beds. These bottom boards are laid in loose in order to facilitate filling and emptying the beds. The side boards (*a* and *b*) are also loose and are held in place by the compost in the bed. The side boards have been omitted from the upper beds shown in figure 5 to simplify the drawing. The beds are usually 5 inches deep and 6 feet wide (*a* to *b*)—sometimes 5 feet— and run the full length of the house, with the exception of the alleys at the ends of the house. The tiers of beds are supported by 2- by 4-inch uprights (*c* and *g*) set at 4-foot intervals (*c* to *d*). The uprights are joined beneath the bottom boards by 1½- by 6-inch bed supports (*k*).

ALLEYWAYS

A space about 30 inches wide is usually provided between the tiers of beds to form a service alleyway, which runs the full length of the house. This alley is used in filling and emptying the beds. An elevated runway (level of *j*) is built in this alley to make it easier to fill the upper beds. Often the house is built lengthwise into a sidehill with the high ground at the level of the elevated runway (*j*). An 18-inch alleyway between the outside walls and the tiers of beds is also provided to facilitate picking.

OUTSIDE DIMENSIONS

The length of the house is usually determined as the result of a compromise between the ideas of a long house, economical to build, and a short house, convenient and economical to fill. Many successful growers consider 65 feet a suitable length. If the house is constructed as shown in figure 5, with two tiers of beds (six beds high, including the floor bed), the width of the house is about 20 feet. Obviously, the height depends on the number of beds in a tier; usually 3 feet is allowed for working space between the top beds and the ceiling. Often several houses are joined together and built alongside each other. When this is done it is customary to make one roof cover four tiers of beds. Two houses joined under one roof in this way are called a double house.

DOORS

There are six doors in a mushroom house—three at each end, one opening at ground level, one at the walk level, and one in the loft (fig. 5).

VENTILATION

Mushroom houses must have ventilation systems that provide gradual changes of air with the least possible direct draft over the beds. Ventilation usually is accomplished by occasionally partly opening the doors and opening the hinged vents (*i*) in the ceiling. To facilitate air circulation the ceiling is sloped upward from the side walls to the ventilators over the center aisle and likewise from one end of the house to the other. In some houses provision is made for drawing the air off the floor and discharging it outside, and the ventilators may be screened to prevent the entrance of mushroom flies.

REFRIGERATION

Several growers have installed small refrigeration plants to assist them over warm spells in the late spring and early fall and a few have cooling plants extensive enough to enable them to grow mushrooms in the summer. The small refrigeration plants are usually based on the washed-air principle, and water pumped from deep wells is used as the cooling agent. The larger plants use mechanical refrigeration, in some cases supplemented with water sprays. In either case the house must be well insulated and the plant must be so designed that it can be cooled without excessive humidity or circulation of air.

HEATING PLANTS

Mushroom growers usually use hot-water heat. The radiation generally consists of four or five pipes running around the house, hung on the inside of the walls, within a few feet of the floor. In view of the recently adopted practice of supplying auxiliary heat at the time of the final fermentation, provision (p. 18) should be made for the occasional use of steam.

MATERIALS

The walls are made of any material that has fair insulating value and will withstand dampness. Some growers make their walls with a single layer of siding, as shown in figure 5. Most use a double wall

286525°—41——2

filled with sawdust or cork. Others use cinder blocks, tile, or other similar material. When the house is built with a ceiling, as shown in figure 5, it is the general practice to cover the floor of the loft with about 5 inches of loose shavings, for heat insulation. The bottom boards and side boards of the beds are often made of cypress to resist rotting.

CAPACITY

The average mushroom house, 65 by 20 feet, with beds arranged in two tiers six beds high, contains 4,320 square feet of bed space. As it takes 1 ton of manure to fill 70 square feet of beds, such a house requires approximately 60 tons of manure. It is essential that the manure capacity or bed space be large as compared to the air space, because a large proportion of manure to air space insures a better heat during the fermentation in the house, and a large capacity makes it easier to maintain a high relative humidity and cuts down the capital investment per square foot of bed space.

CAVES AND ABANDONED MINES

In France mushrooms are grown almost exclusively in abandoned underground quarries. Sandstone and limestone caves have been used in the United States for growing mushrooms for more than a quarter century (fig. 6). The advantages of using caves or mines

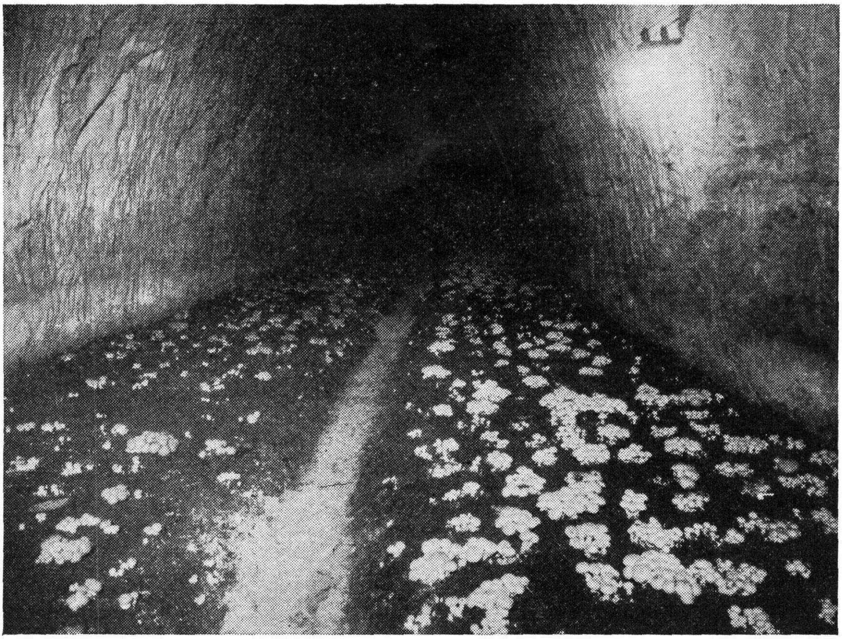


FIGURE 6.—Floor beds in a sandstone cave, St. Paul, Minn.

for growing mushrooms are the small initial investment and uniform low temperatures for year-round culture without expensive artificial refrigeration. The disadvantages are: The difficulty of disinfecting and ventilating; the fact that an adequate pasteurizing or sweating-

out cannot be obtained in the bed; dripping and excessive humidity in the summer; the fact that bed temperatures cannot be raised during the spawn run; and that distances from railroad facilities, markets, and manure supply are frequently great. The most serious of the disadvantages is the inability to properly sweat out the compost in underground caverns or mines. Largely because of this, growers using the special mushroom house have been able in the past to obtain consistently better yields than growers operating in caves.

A few years ago, however, a new system for cave culture was developed that combines the advantages of the high yield obtained in special houses with the economy of operation inherent in cave culture. The new system is called the two-zone or tray system.

FIGURE 7.—Movable-tray (or two-zone) system of raising mushrooms in a limestone cavern near Pittsburgh, Pa.

If this method is used, the finished compost is placed in movable trays instead of stationary beds, so as to allow the grower to sweat out his compost and fumigate it in a specially equipped room near the entrance of the cave and then to transport the trays into the caves where they can be more economically cared for during the growing period (fig. 7). The advantages of this procedure will be better understood after reading the discussion of sweating out and fumigation (pp. 16 and 32). The two-zone system is also being adopted where growers make use of abandoned factories suitable for growing mushrooms but not so well suited for sweating-out the compost.

SELECTING AND STORING MANURE

Commercial mushroom growers use horse manure with straw bedding almost exclusively as the raw material for mushroom compost. Practical experience has led them to prefer manure from

grain-fed horses bedded with a moderate amount of wheat straw. Manure with too much straw has a tendency to dry out and cool off because of excessive evaporation. Good mushroom crops have been obtained from manure with rye straw, oat straw, or even pine shavings as bedding, but these materials require special treatment. Rye straw is usually longer and more difficult to break up than wheat straw; oat straw breaks down very rapidly and has a tendency to overheat and become moldy; shavings manure makes a compact heap and requires more thorough aeration than straw manure. Certain growers have successfully handled strawy or "long" manure from racing stables by heaping it twice as high as ordinary manure at the beginning of the composting period. In large cities, such as New York, Philadelphia, and Chicago, the manure is handled by brokers who contract with the stable owners and resell by the carload to truck gardeners and mushroom growers (fig. 8).

Whenever possible, the manure should be composted as soon as a rick is assembled large enough to fill the mushroom house. If storage is necessary, the method most generally practiced is to pile the manure into large compact heaps from 8 to 10 feet high, containing at least 90 tons. The heaps are then covered with several inches of soil and allowed to stand undisturbed except for an occasional watering of the outside layer. Manure handled in this way can be successfully stored for 3 to 4 months. Apparently the manure remains in better condition if moist, anaerobic conditions are maintained inside the rick to check fermentation and keep the compost "green."

SYNTHETIC COMPOST

For several years commercial mushroom growers and State and Federal agricultural experiment stations have been experimenting with artificial composts to replace horse manure in mushroom culture. The work along this line has recently been summarized in Pennsylvania State College Bulletin 365. As a rule, the raw materials for synthetic composts are approximately as costly as horse manure. More labor is required in the preparation of artificial compost, and in most cases the yield of mushrooms is less than with horse-manure compost. For these reasons very few commercial growers have found it profitable to make synthetic compost except in small-scale experimental trials.

Usually straw is the chief source of carbohydrate and mineral nutrients in making artificial compost. The most important features of the process are: Wetting the straw with about three times its weight of water; adding enough nitrogenous fertilizer to furnish nitrogen in an amount equivalent to about 1 or 2 percent of the dry weight of the straw; adding other materials (see p. 12) to make the compost like horse manure; maintaining a neutral or slightly alkaline reaction within the heap; and composting under conditions of aeration, moisture, and temperature, such as are obtained in the conventional heaps of horse manure composted for mushroom culture.

In making synthetic compost the first objective is to attain a condition of moisture and compactness similar to horse-manure compost. Two methods have been successfully used for wetting the straw, the sprinkling method and the soaking or vat method.

SPRINKLING METHOD

When the sprinkling method is used, the straw is at first forked over and sprinkled, usually by two or three men, so that every forkful receives some moisture. It is very difficult to moisten the dry straw evenly. If too much water is applied the water will simply run on through the straw and out the bottom of the heap. After the straw has become damp and has been allowed to warm up it will take up water much more readily. For this reason it is advisable to add only part of the water and part of the urea when the heap is first assembled. The remainder can be more uniformly distributed during subsequent turnings.

FIGURE 8.—Chopping straw for making synthetic compost, Arlington Experiment Farm, Arlington, Va.

The compost heaps are usually made a few feet higher at first with straw compost than with manure. This is done to partly compensate for the open texture of the straw compost. After the straw has been dampened and the chemicals added, the composting proceeds in much the same manner as with horse manure. The straw heaps can be made more compact by chopping up the straw with a silage cutter (fig. 8), by adding soil or a fine material such as wheat or brewers' grain or by tramping down the straw compost in layers, a few inches at a time. The object is to attain an end product which looks and feels as much like properly composted horse manure as possible.

VAT METHOD

With the vat method, a shallow concrete or wooden vat, which is large enough to contain several bales of straw, is constructed. The

bales are wet by being soaked in the vat. Some difficulty is experienced, as the bales float high on the water and tend to swell and burst loose from the bale wire. The floating can be at least partly overcome by weighting down the bales, and they should be turned over occasionally to expose all sides to the water. Before the bales are soaked, the wires should be loosened to allow for swelling.

The soluble nitrogen fertilizer, in most cases urea, is added to the water in the vat. The amount of water added to the vat should be measured so that nearly all of the liquid is taken up in 24 hours. The bales are removed after a day's soaking, and the wet straw is made up into a compost heap. All of the liquid remaining in the vat should be sprinkled over the heap during the first turning. Following this, the compost is handled in the same manner as synthetic manure made by the sprinkling method.

A modified vat system has been successfully developed by one large grower in which the floor under the compost heap is drained into a concrete pit, which allows the grower to pump water and soluble fertilizer over the straw again and again until the required amount of liquid is taken up. This procedure combines the best features of the sprinkler and vat methods.

MATERIALS ADDED

Although different experimenters have used various mixtures of material (and followed various routines) wholly satisfactory results have not been obtained, and the problem is still in the developmental stage. The writer has obtained the best yields of mushrooms from compost made of the following materials in the proportions shown:

	Pounds
Wheat or rye straw	1, 000
Water	2, 000–3, 000
Urea	10
Dried blood	40
Ground limestone	20
Superphosphate	40
Screened soil	500
Horse manure	100

The urea is dissolved in water and applied during the first turning of the sprinkling method or added to the water in the vat. The remaining fertilizers are mixed with the soil and scattered as uniformly as possible throughout the heap during the first or second turning. Urea and dried blood appear to be preferable to several other sources of nitrogen. Comparisons have been made with ammonium sulfate, calicium cyanamide, Adco, cottonseed meal, fish scrap, Peruvian guano, goat manure, poultry manure, Milorganite, whale guano, sheep manure, and tankage. More complete decomposition and better yields are obtained with blood in the formula than with urea alone. The soil is added to help make the mixture compact and to act as a carrier in the distribution of the dried blood, superphosphate, and limestone. The ground limestone and superphosphate are not as essential as the blood and urea but prevent an acid fermentation and seem to aid the run of spawn and maintain a high average yield.

Other mineral elements such as magnesium, or potassium, or traces of copper, iron, zinc, manganese, and boron may be beneficial, but evidence of their value has not yet been obtained. The experiments reported in Pennsylvania State College Bulletin 365 suggest

that the addition of from 100 to 400 pounds of wet wheat, or brewers grain, may be a valuable adjunct to the foregoing formula.

BED SPACE AND YIELDS FROM SYNTHETIC COMPOST

Compost made up with materials in these proportions will fill about 200 to 250 square feet of bed space and is the equivalent of 2 or 3 tons of horse manure.

Under favorable conditions an average yield of 1½ pounds per square foot is not exceptional. In experimental trials at the Arlington, Va., Experiment Farm, average yields of this magnitude have been obtained from test beds replicated eight times, representing duplicate compost heaps. Some of the individual plots of synthetic compost have yielded more than 2 pounds per square foot. Over a period of years, however, the artificial compost has in these experiments yielded only about two-thirds as well as horse manure per unit area

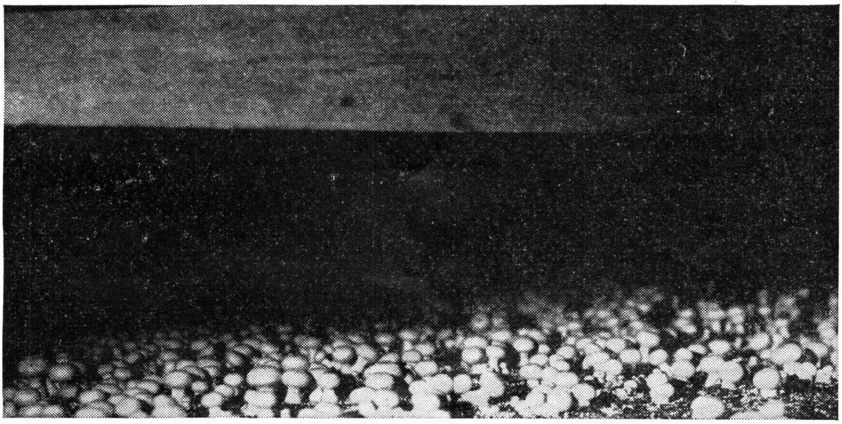


FIGURE 9.—Mushrooms on an experimental bed of synthetic compost.

of bed surface. Part of this difference is doubtless due to the greater difficulty in obtaining favorable conditions of temperature, moisture, and aeration in synthetic compost heaps during composting. Likewise, a part of the difference may be due to the fact that a unit of bed space filled with synthetic compost usually contains less organic material by weight than horse-manure compost. Moreover, synthetic compost usually does not heat so well during sweating out as horse-manure compost.

When horse manure is mixed with synthetic compost the yield of mushrooms is usually better than with synthetic compost alone. Fairly normal yields can be expected when the mixture contains as much as one-half horse manure (fig. 9).

MUSHROOMS NOT ADAPTABLE TO WATER CULTURE

In recent years considerable popular interest has been aroused regarding the commercial possibilities of growing plants in water culture. At the present time it seems highly improbable and perhaps impossible to grow mushrooms in this manner. Mushrooms must have carbohydrates in their culture medium in addition to the mineral elements required by green plants. Thus it is necessary in preparing a water-culture medium for mushrooms to add some form of carbo-

hydrate, such as cellulose, starch, or sugar, which are not at all essential for higher plants. When these elements are present the water cultures become overrun with contaminating molds and bacteria that invariably crowd out the slow-growing mushroom mycelium. The only known method of preventing this is to sterilize the water culture and filter out all contaminating spores from the air. This can be readily done in the small glass bottles used for making mushroom spawn, but to maintain pure-culture conditions on a large enough scale for commercial mushroom culture would require expensive equipment and elaborate precautions entirely out of proportion to the possible returns from the sale of mushrooms.

COMPOSTING IN THE RICK

Composting the manure or synthetic medium is probably the most variable operation in mushroom culture. Manure assembled for

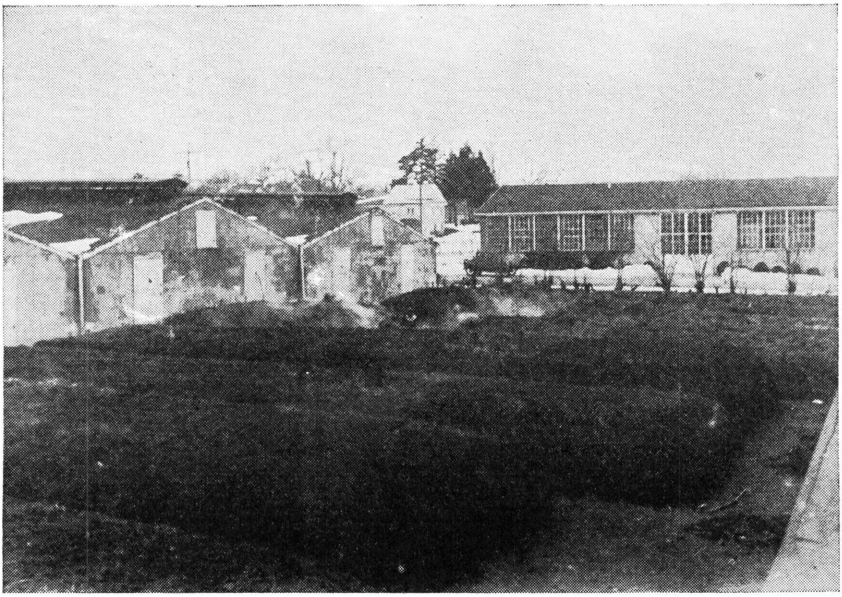


FIGURE 10.—Manure assembled in 90-ton heaps or ricks for composting.

different heaps or ricks, or even for different parts of the same rick, is seldom exactly alike. Successful growers attempt to allow for these differences by accommodating their composting procedure to the kind of manure. They keep in mind what they consider ideal composting conditions and ideal texture and appearance of the finished compost rather than a set procedure for handling the manure.

The most important factors affecting the compost that may be controlled by the grower are aeration, moisture content, and temperature. These are largely dependent on the size and shape of the rick, its height, compactness, the amount of water added during turning, and the number of days between turnings. The lateral dimensions of the heap are usually determined by the space available for composting and the amount of bed space to be filled. Ricks for commercial mushroom culture usually contain 60 to 100 tons of manure and are about 20 feet wide and 40 to 60 feet long (fig. 10). The height

of the rick depends somewhat on the texture of the manure. The average manure with a moderate proportion of straw to droppings is piled up from 4 to 5 feet high when first assembled. Manure containing an excess of straw has a loose texture and will shrink to one-fourth of its bulk during composting. Therefore manure of this type is piled up 5 to 7 feet high when first assembled and should be weighted down with a layer of soil or boards during the early stages of fermentation. Some growers always spread a layer of soil over the top of the rick to make it more compact and to help conserve the moisture; others consider the soil unnecessary and regulate the moisture entirely by watering during the composting. In either case, inasmuch as the manure shrinks during composting, the rick is only about 3 feet high at filling time.

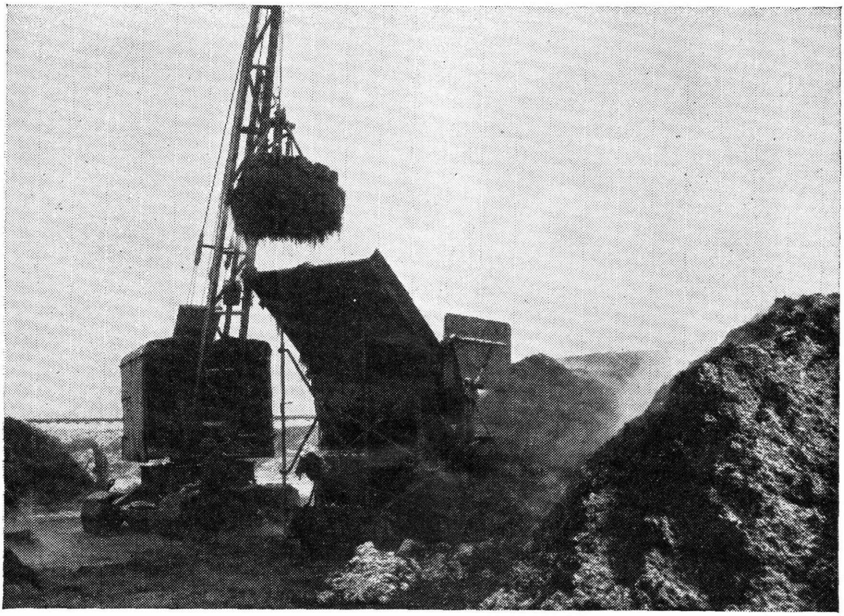


FIGURE 11.—Machine used for mixing and aerating mushroom compost during turning.

The ricks are usually allowed to stand undisturbed for 10 days after they are assembled before the first turning. The turning is usually done by hand although a few growers use special machines (fig. 11). During the first turning, water is applied to the dry straw, the caked manure is broken up, and the sides of the heap are turned toward the center. This process is repeated at intervals of from a week to 10 days until the compost is in proper condition to go into the house. The object of the turning is to aerate the manure, break it up, thoroughly mix it, and maintain a moderate moisture content throughout the rick. Success or failure depends very largely on the moisture content of the rick during fermentation and at the end of the composting period.

Excessive watering causes a "greasy" compost, sometimes called "black butter," which favors the development of a disease called plaster mold on the bed. This greasy compost may be difficult to dry out sufficiently to enable mushroom mycelium to run. On the

286525°—41——3

other hand, too little water slows down the fermentation. The average grower maintains about 150 to 250 percent water (on a dry-weight basis) in his heap, although this differs with different seasons, different types of manure, and different stages in the composting period. In general, the manure should be moist but not wet, and a larger water content is allowable at the beginning of the composting period than at the end. As a rule, heavy watering is confined to the first turnings. The objective toward the end of the composting period is to obtain a condition somewhat more moist than the optimum for the growth of mycelium, in order to allow for a loss of water during the final fermentation in the house.

The grower's practical test for this moisture content is to squeeze a ball of compost tightly in the hand. If the hand is not moistened the compost is too dry; if water oozes out freely between the fingers the compost is too wet. Manure in a desirable condition contains about 175 percent as much water as dry matter. Experienced growers know the great necessity of avoiding a soggy condition toward the end of the composting period. Such a condition is one of the most common causes of failure. Mushroom mycelium will not run in wet manure, and the compost will not heat properly in the bed. During cloudy weather ricks often become more moist toward the end of the composting period without any water being added. Growers refer to this change as "taking up water." Probably the apparent taking up of water is really an accumulation of water formed as a result of the decomposition of the organic material.

The most desirable interval between turnings and the duration of the composting period depend on the nature of the compost. Weekly turnings are generally considered most satisfactory, but if the manure is short a uniform compost may be obtained with intervals of 10 days between turnings. In the Pennsylvania region, where manure is shipped in by the carload, it usually has been handled several times before the grower receives it. Under these conditions a composting period of 25 to 35 days is generally sufficient. This would include 10 days from the time of assembling to the first turning and two or three turnings at weekly intervals. When long manure is obtained fresh from the stables, 6 weeks may be necessary with four or five turnings. In any case the real criterion of the end of the composting period is the condition of the compost. Well-composted manure is fairly uniform in color and texture, a dark chocolate-brown moderately speckled with white; the straw is pliable enough to shear off readily when torn crossways; when squeezed, the compost just moistens the hand without any water running out and at the same time is sufficiently moist and decomposed to remain in a ball when so molded. When this condition is reached, the compost is ready for making beds and should be taken into the house about 3 days after the last turning.

PASTEURIZING OR SWEATING OUT IN THE BED

A few of the larger growers run the manure into the house from the ricks on a series of belt conveyors driven by electric motors, but most of them use bushel baskets set in a row on long, narrow cars that run on light, narrow-gage tracks (fig. 12). The manure is placed in the beds at the rate of 1 bushel to approximately 2 square feet of bed space. If the compost is wet or has approximately the correct moisture content, it is allowed to lie in the beds loose or only slightly

packed during the heating process. If it is too dry, it is packed to help retain the moisture.

A standard house is usually filled in 1 or 2 days, the house is then closed up tightly, and the manure is allowed to go through a final fermentation for a few days. High temperatures are generated inside the house by the manure, and the whole procedure is referred to as "pasteurizing," "sweating out," or "putting through the heat." This heat serves four purposes: (1) It allows the grower to dry out the manure if it is too wet; (2) it eradicates many harmful fungi, which have been taken into the house with the manure; (3) it brings about a healthier and more rapid run of spawn because of a more favorable biological balance or nutritional condition in the compost, and (4) it drives insects and mites to the surface of the bed, where they can be killed by fumigation with cyanide or sulfur dioxide.

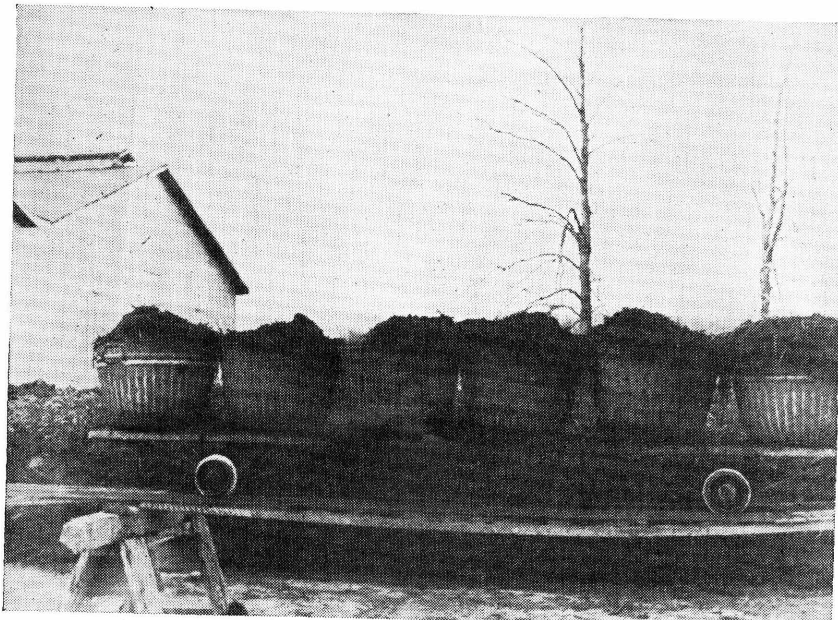


FIGURE 12.—Filling a mushroom house by means of a narrow-gage truck and baskets.

TEMPERATURE

The most favorable temperatures in the manure during the sweating-out period appear to be between 125° F. and 140° F. Higher temperatures than this may be injurious to the subsequent growth of mushroom spawn. Lower temperatures fail to eradicate insect pests.

In a tightly constructed mushroom house the manure attains a temperature of 130° F. in from 1 to 3 days after the house is closed up. Most of the heat is generated by the fermenting manure although some additional heat is usually supplied from the hot-water radiation provided in mushroom houses. Because the manure is actively generating heat, the temperature within the beds is usually 10° to 15° F. higher than the temperature of the surrounding air. This temperature differential becomes less from day to day as the more

readily available carbonaceous material in the manure becomes oxidized. There is also a tendency for a temperature gradient to develop from the top of the house to the bottom. If no provision is made for vertical circulation of the air, the temperature in the top beds may be as much as 15° F. higher than the temperature in the lower beds. This differential can be reduced to 5° F. by forced vertical circulation of the air, which is usually attained by placing in the aisles electric fans set vertically or at an angle of 45°.

When the grower relies principally on the heat in the manure to obtain the desired temperatures, he frequently encounters difficulty in attaining a high enough temperature (130° F. for several hours) in the air near the floor to eradicate harmful fungi, insects, and mites without running a risk of injuring the manure by overheating (more than 145° F.). This can be readily appreciated when it is remembered that there may be a 15° F. differential from inside the bed to the air surrounding the bed, and a 5° to 10° differential from the top bed to the bottom bed. On the other hand, most growers have no difficulty raising the temperature inside the beds sufficiently (to 125° F.) to drive the insect pests out of the compost. Under these circumstances fumigation with sulfur or hydrocyanic acid gas has proved very effective, although neither of these fumigants penetrate deeply into the manure. To obtain best results, the gas should be released in the house when the temperature of the beds has reached a maximum, usually referred to by commercial growers as peak heat.

Fumigation during peak heat is almost a universal practice among commercial growers. A detailed description of the methods of fumigation during peak heat is given in the subsequent discussion of insect control (p. 31).

During the past 10 years experiments at Arlington Farm, Va., have shown that a satisfactory final fermentation can be obtained without fumigation by supplying supplementary heat in the form of live steam toward the end of the sweating-out period. For best results this supplementary heat should be delayed until 4 or 5 days after filling the house, or until the differential between the air temperature and the bed temperature has fallen to about 5° F. Holding the air temperature at 130° F. for 2 days at this time is sufficient to eradicate insects and most harmful fungi and will not raise the temperature within the top beds to more than 140° F. with forced vertical ventilation.

The delay in the use of supplementary heat until towards the end of the sweating-out period is recommended because at that time there is less danger of overheating the manure and there is also a smaller differential between manure temperature and air temperature. It is necessary to constantly guard against the temperature in the beds getting out of control and going over 145° F. The damage that may be done by overheating the beds can hardly be overemphasized. A few hours with a temperature of over 150° F. will frequently cause a crop failure.

MOISTURE

The desired moisture content of the air during the sweating-out will depend on whether the compost has been put into the beds too wet, too dry, or just right, according to the judgment of the grower. If the manure has been placed in the beds too wet, it can be dried out somewhat by prolonged heating, with occasional ventilation to bring in

dry air. A dry atmosphere is not often required, as the heat generated in the beds tends to dry them out. Usually the air should be as nearly saturated as possible. Condensation on the floors, walls, or ceiling determines the upper limit of humidity that can be obtained. A poorly insulated ceiling frequently causes dripping on the upper beds. If it is not feasible to apply more insulation to the ceiling, condensation can be prevented from reaching the beds by hanging a false ceiling over them. The circulation of the air necessary to prevent temperature layering will oftentimes cause drying out of local areas in the beds. This should be avoided wherever possible. If supplementary heat is available, the grower need not hesitate to water the beds during sweating out; but if no supplementary heat is available, watering must be done with caution to avoid prematurely cooling the beds.

VENTILATION

During sweating out the thermophilic microbial flora in the compost is extremely active, as evidenced by the heat produced in the beds. Carbon dioxide is liberated in such large quantities that one frequently finds it difficult to breathe normally after a few minutes in the house. The compost does not seem to be adversely affected by a moderate decrease in oxygen or increase in carbon dioxide but is distinctly injured by a complete absence of oxygen. A few changes of air each day are probably sufficient. Excessive ventilation should be avoided, because it tends to dry out the beds and lower the temperature.

DURATION OF SWEATING OUT

Best results are obtained if sweating out is prolonged at least 4 or 5 days, preferably 7 or 8 days if the compost is not drying out excessively. After 4 days, samples of the compost are tested for pH value at daily intervals. At this time the pH value will recede at a rate of about 0.2 every day. Sweating out may be discontinued and the house allowed to cool off as soon as the pH value has fallen below 8.0.

SPAWNING AND CASING

The spawn is inserted in the beds as soon as the temperature in the compost has receded to 75° F. Most spawn makers advocate using spawn pieces about one-half as large as a hen's egg and spacing them about 8 inches to 1 foot apart in the bed. An imperial quart bottle of spawn supplies about 35 to 40 such spawn pieces. The pieces are inserted in the bed about 1½ inches from the surface. After the spawn is inserted, the temperature of the bed is usually maintained at about 70° for a week or 10 days to insure a good "catch" of spawn. The temperature is then dropped slowly until the desired cropping temperature is reached. The mycelium grows most vigorously at about 75° in both sterilized and unsterilized compost (fig. 13), but in most cases it is not desirable to maintain a temperature as high as this for more than a few days because of the increased insect activity at the higher temperature, the tendency for the beds to dry out excessively, and the possibility of aggravating truffle disease.

The casing of the beds consists of simply spreading soil about 1 inch thick over the beds from 2 weeks to a month after spawning. It is evident from the widespread distribution of the industry that suitable casing soil may be found in most sections of the United

States. The most important characteristics of soil for casing are porosity and water-holding capacity. A good casing soil will tenaciously retain water and dry out uniformly without cracking or forming a crust on the surface. Neutral loam soils with a fair amount of organic matter make the best casing soil. The soil should never be allowed to become puddled or airtight. Subsoil and acid sandy soils should be avoided. The practice of neutralizing soil with limestone has gained favor in recent years. If the pH value of the soil is less than 6, it should be neutralized by adding powdered limestone. The addition of 1 or 2 percent of limestone is usually sufficient (fig. 14).

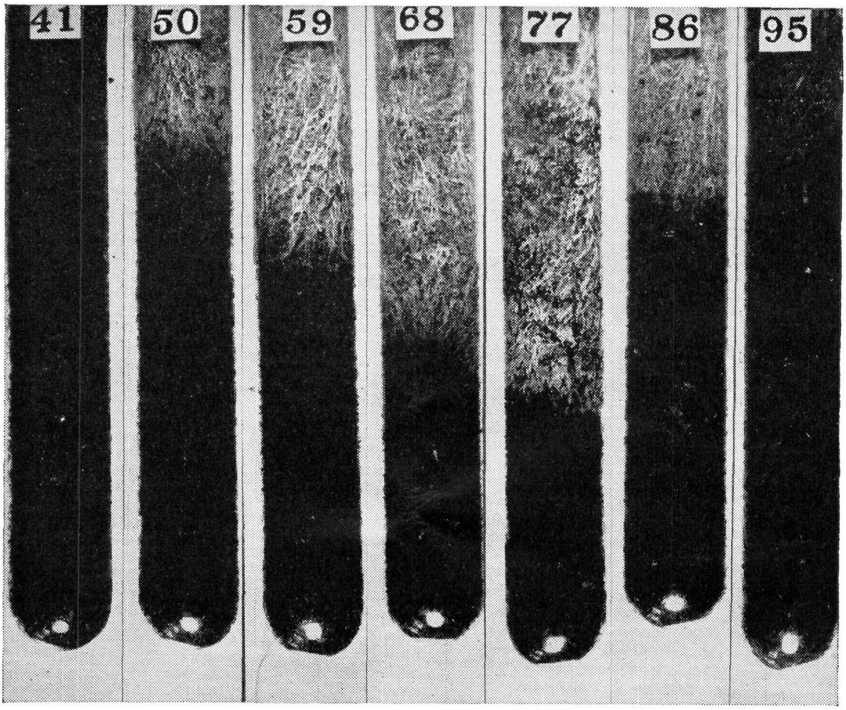


FIGURE 13.—The effect of temperature on the rate of growth of mushroom mycelium in compost. The numbers at the top of the test tubes refer to the incubation temperature in degrees Fahrenheit.

Many growers purchase and maintain small fields especially for casing soil. After stripping the upper 6 inches of a part of the field for casing soil they pass on to other parts in succeeding years. Meanwhile if the subsoil of the stripped portion is of suitable texture, it is prepared for use a second time by liming if necessary and by turning under cover crops to add humus to the soil. A rotation of this kind is usually planned so that an interval of 4 or 5 years elapses before soil is taken a second time from that part of the field. It is important to make sure a field selected for casing soil is not contaminated with the fungus causing the mycogone or bubbles disease of mushrooms. The accepted practice is to avoid all fields that have been previously fertilized with spent mushroom manure or that may be contaminated by means of spores carried by cattle, horses, drain water, or other agen-

cies. These precautions are especially necessary in congested centers of mushroom growing. If there is any doubt about the presence of the fungus in the soil it should be used on small test beds before risking its use on a large scale. When no *Mycogone*-free soil is available the fungus may be eradicated from the soil by heat treatment (see p. 28). In a disease-infested area care must be taken from the digging of the soil to the screening and placing on the beds to prevent the soil from coming into contact with contaminated tools.

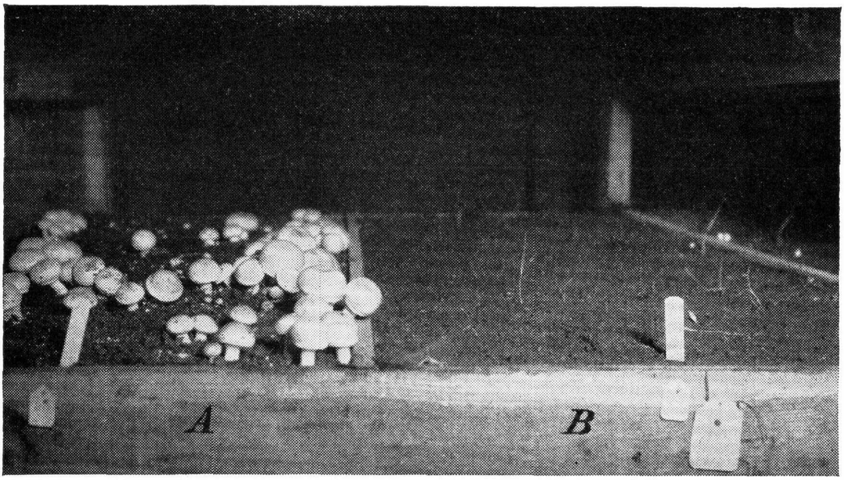


FIGURE 14.—The effect of acidity in the casing soil; *A*, neutral soil: *B*, acid soil.

GROWING CONDITIONS

TEMPERATURE

The temperature at which the house is held largely determines the length of the growing period and has considerable influence on the quality of the mushrooms. If the temperature is kept between 45° and 55° F. good beds continue to bear mushrooms for 4 or 5 months, whereas in a house held at 60° to 65° the beds exhaust themselves in 3 months. At the lower temperatures, as a rule, the mushrooms grow somewhat larger and are distinctly firmer and heavier than those grown at the higher temperatures. The total yield is approximately the same, with perhaps a slight advantage in favor of the beds held within the low temperature range. When two or more crops are grown in 1 season, time is an important consideration; and the beds must be kept at above temperatures. The practice of maintaining a uniform growing temperature is widely favored, although many growers prefer to bring on successive growths of mushrooms by raising the temperature 5° or 10° for a day and then allowing it to drop back to the usual growing temperature. The temperature limits at which the common cultivated varieties of mushrooms can be grown are 45° to 68°. Lower temperatures delay the crop but do not permanently injure the beds. On the other hand, during the time when the mushrooms are on the beds a period of more than a few days with a temperature in the house over 70° will often injure the crop seriously.

HUMIDITY

The relative humidity in the average mushroom house during the bearing period ranges from 70 to 80 percent. This condition is easier to maintain in some houses than in others, because of the difference in the exchange of air through cracks and crevices and differences in the proportion of air space to bed surface. When the humidity is allowed to drop much below 70 percent the casing soil has a tendency to dry out too quickly, and the surface of the mushrooms becomes tough and, under extreme conditions, cracked and seamed. Conversely, if too high a relative humidity is maintained, the mushroom disease known as spot will be aggravated by the reduced rate of evaporation of the contaminated water spattered on the mushrooms during the watering of the beds.

WATERING

Procedure in watering mushroom beds is governed largely by two objectives: Maintaining in the soil the proper moisture content to induce therein an abundant growth of healthy mushroom strands or rhizomorphs; and minimizing puddling of the soil and the appearance of spots and blemishes on the surface of the mushrooms caused by water spattered on the growing mushroom caps. Usually, water is first applied to the beds shortly after they are cased. At this time the beds are watered lightly every day until there is just sufficient moisture in the soil to cause normal strand formation throughout the soil layer. This moderate moisture content is maintained until the mushrooms begin to appear. Care should be taken to avoid an excess of water in the soil at this time, as it may prevent normal strand formation and seriously reduce the subsequent yield of mushrooms. The amount of water necessary to maintain the proper moisture content is different for different soils and in different localities and seasons. It depends on the relative humidity and rate of movement of the air in the house, the moisture content of the compost and texture, physical conditions, and water-holding capacity of the soil. In general, several light waterings are preferable to a few heavy ones because of the danger of excess water percolating through the soil and causing the formation of a wet layer of manure under the soil. Such a layer may prevent the healthy mushroom mycelium lower in the bed from growing up in the soil. Puddles of water on the bed are also objectionable because they tend to make an airtight crust form on the surface of the soil, stimulate the development in the soil of a harmful green mold, and cause submerged pinhead mushrooms to turn brown and die. On the other hand, if the soil is too dry or if only the upper layer is moist, fewer mushrooms will develop, and the first mushrooms to come up will have a tendency to form beneath the soil layer rather than on the upper surface.

After the mushrooms begin to appear they usually develop in sudden outbreaks at intervals of about a week. These outbreaks are called "flushes" or "breaks" and are followed by periods during which there are only a few mushrooms on the beds (fig. 15). There are several systems of watering in relation to these breaks. Some growers water only between breaks so as to avoid wetting the mushrooms. Others water lightly two or three times a week regardless of the breaks. Many follow a compromise system of watering regardless of the breaks during the first three breaks. During this period spotting of mush-

rooms is not serious because the fresh mushroom mycelium is vigorous, and harmful fungi and bacteria are comparatively scarce in the soil. Thereafter, watering is done only between breaks. In any case, when water is applied to the beds while mushrooms are growing, a gentle shower is used to avoid spattering soil onto the caps of the mushrooms, and ventilation is increased after watering until the droplets on the mushroom caps are evaporated.

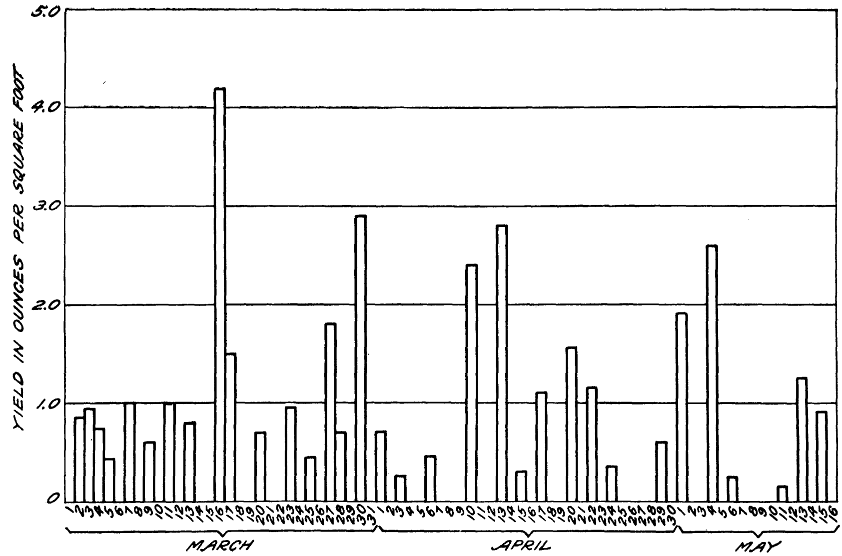


FIGURE 15.—The daily yields of mushrooms from a 10-square-foot test bed at the Arlington Experiment Farm. Note the cycles of growth referred to by growers as flushes or breaks.

VENTILATION

Considerable ventilation is necessary in growing a good crop of mushrooms, and it is advisable to give as much ventilation as possible without interfering with temperature and humidity control or causing excessive evaporation from the beds by cross drafts. Usually it is easier to ventilate without special precautions in the spring and fall months. When the temperature outside the mushroom house is higher than that inside, the fresh air will become damp upon entering the house. Conversely, cold air brought into a warm mushroom house absorbs moisture and will have a tendency to lower the relative humidity inside the house.

SANITATION AND DISINFECTION

As congested centers of mushroom growing develop (fig. 16), it is becoming more and more apparent that cumulative losses caused by fungi and insect pests can scarcely be avoided unless a carefully planned program of disinfection and sanitation is made a part of the routine of cultural practice. It is advisable to thoroughly disinfect the composting grounds and the mushroom house between crops and to take special precautions to prevent the contamination of casing soil and water.

A few growers have concrete composting surfaces, but usually the manure is composted on the bare ground, and a sanitary condition is

maintained by keeping the ground free from old manure and standing water between crops and by thoroughly drenching the soil with a disinfectant a few weeks before assembling the manure. A solution of formaldehyde made by dissolving 1 pint of fresh formalin in 15 gallons of water has satisfactory germicidal properties for this purpose and in addition has the advantage of being noncorrosive to metals and of remaining only temporarily in the soil.

It is almost a universal practice to thoroughly disinfect the inside of the mushroom house a few weeks before filling time either by burning sulfur or releasing formaldehyde gas. In most cases effective fumigation may be obtained by either method, especially under warm, damp conditions, but both sulfur fumes and formaldehyde gas are injurious

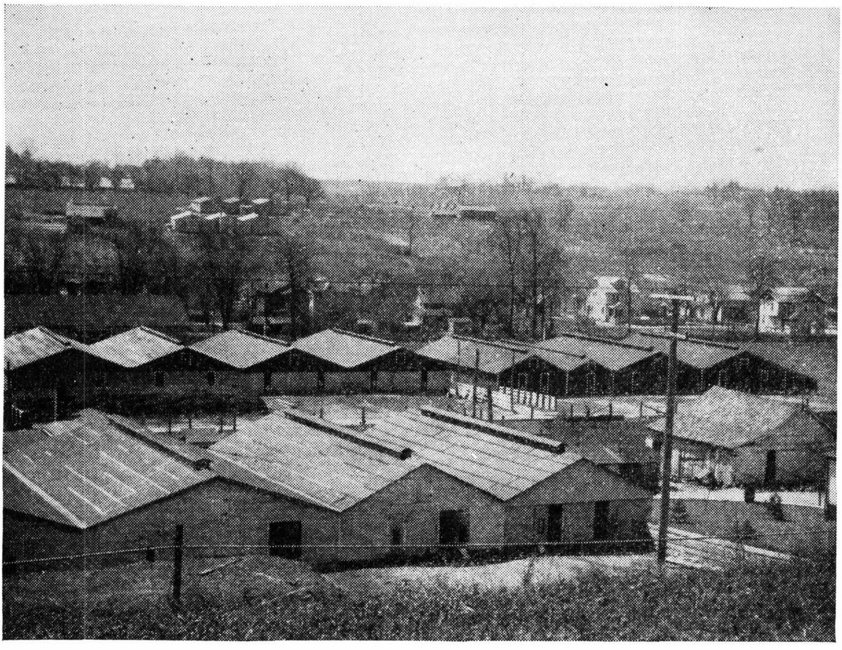


FIGURE 16.—Mushroom houses near Taughkenamon, Pa.

to growing mushrooms, and special precautions are necessary when fumigating a house adjacent to one in which a crop is growing. Numerous case histories indicate that formaldehyde is preferable to sulfur for controlling the truffle disease.

When sulfur is used, it is usually burned at the rate of 5 pounds per 1,000 cubic feet of air space by one of the methods described in the discussion of insect control (p. 31).

Fumigation with formaldehyde is accomplished by vaporizing commercial formalin (40 percent formaldehyde solution in water) at the rate of 1 quart to 1,000 cubic feet of air space. The formalin is usually placed in pails or tubs along the alley and vaporized by adding crystals of potassium permanganate at the rate of 1 pound per quart of formalin. As in fumigating with sulfur, the crystals should be placed in paper bags, and all preparations for quickly leaving and closing the house should be made before the gas is released. Exposed lights should

not be used in the house because formaldehyde gas is explosive under certain conditions.

Another method of fumigating with formaldehyde is to mix formaldehyde (commercial 40-percent solution) with an equal amount of water and vaporize the formaldehyde from the mixture by boiling it off from a small boiler set up outside the mushroom house. The formaldehyde vapor is piped directly into the house.

While the crop is being picked, all mushrooms affected with bubbles should be carefully removed from the house and burned, to prevent the spread of the disease. After doing this work, the men should thoroughly disinfect their hands. It is also advisable to burn all mushroom refuse. After each crop all traces of spent manure should be removed and disposed of so that none will be used on fields near the mushroom house or where it can possibly contaminate prospective casing soil.

The water supply also should be carefully guarded against contamination with fungus spores or any traces of grease or oil that might cause diseased or deformed mushrooms.

For general disinfecting around the packing house or disinfecting workmen's hands or diseased areas on a bed, a solution of calcium hypochlorite, 10 ounces to 50 gallons of water, is frequently used.

HARVESTING, PACKING, AND MARKETING

Comparatively little skill is required in picking mushrooms. They are usually gathered at a stage of growth about 12 hours before the veil would normally rupture. Mushrooms in the same stage of growth often range from 1 to 3 inches in diameter; so the principal consideration is not the size of the mushroom but whether it has finished growing in the closed form. Mushrooms are pulled rather than cut. After a mushroom or clump of mushrooms is picked, the fleshy stump is carefully removed, and the hole is usually filled with fresh soil. The removal of these stumps is important, because their presence in the bed favors the development of green mold in the soil and the green mold prevents the formation of new mushrooms in the moldy area. Large numbers of button mushrooms from one-eighth to three-eighths inch in diameter die off, even on normal beds, presumably because of the crowding-out or breaking of the mycelial strands connecting the young mushrooms with their supply of nutrition in the compost. With a little practice, these mushrooms are easily distinguished from healthy buttons, and they should be removed from the bed for the same reason that the dead stumps are removed. This job, which growers call "trashing," must be done thoroughly at frequent intervals in order to obtain maximum crops.

Most of the mushrooms sold in the United States are marketed fresh, although a well-established canning industry has developed in the last 25 years to take care of the demand for canned mushrooms. Fresh mushrooms are sold on the basis of weight, in 3-pound, 2-pound, and 1-pound climax baskets and in paper cartons (fig. 17). In recent years smaller packages are gaining favor both with the dealer and the consumer.

When packed fresh, they are usually sorted according to size, freedom from blemishes, and certain other requirements. In most large cities they are sold on a commission basis through produce dealers.

In smaller cities they are sometimes shipped directly from the grower to hotels. Shipment from surrounding States into Chicago is usually made by express, whereas nearly all of the mushrooms shipped from Pennsylvania into New York City are taken directly from the grower to the commission dealer in trucks.

Often both the grower and the consignee benefit from the use of United States standards for mushrooms when handling the best grade. Mushrooms may be graded and the containers marked United States No. 1 provided they contain good-quality mushrooms larger than 1 inch in diameter. They may be marked United States Small, United States Medium, United States Large, or United States Extra Large if they conform to the quality requirements under United States No. 1 and the following size specifications: Small, under 1 inch in diameter; medium, 1–1⅝ inches; large 1⅝ to 3 inches; extra large, over 3 inches.

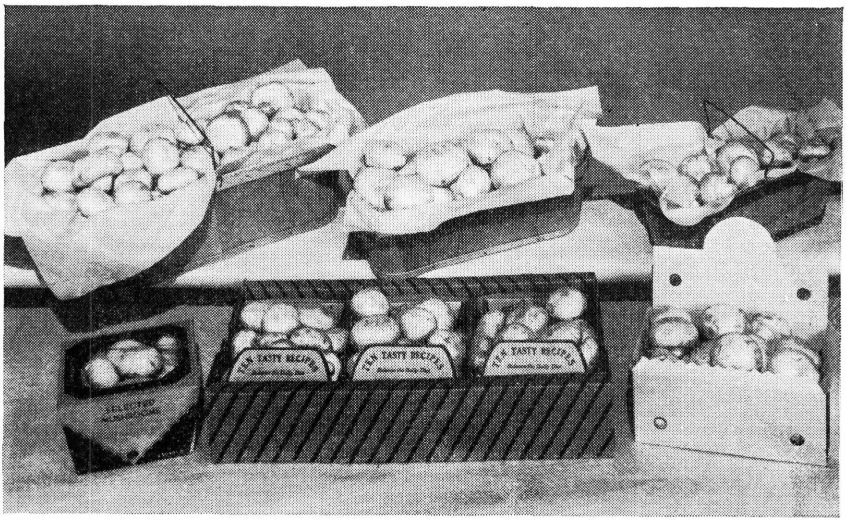


FIGURE 17.—Mushrooms packed for market.

Packages in any of these grades should contain fresh mushrooms of similar varietal characteristics which are not badly misshapen, are free from disease, insect injury, open cap, spots, and damage caused by dirt or by mechanical or other means, and have stems properly trimmed and not more than 1¼ inches long.[1]

Mushrooms are canned in Pennsylvania, Delaware, New York, Ohio, Minnesota, and Colorado. Usually they are received at the cannery and processed on the day they are picked. Button mushrooms are preferred for canning. These are sorted out on a moving belt, carried immediately to vats, where they are preheated until they have shrunk about 40 to 50 percent in bulk, placed in cans, weighed, and processed.

COSTS AND RETURNS

Mushroom growers must meet many of the economic difficulties that confront the producers of other perishable crops. The cost of production is difficult to predict, and the sale price is almost entirely

[1] Copies of the latest United States specifications for mushroom grades and sizes, including the definition of terms and the percentage of tolerance of offtypes, can be obtained on request from the Agricultural Marketing Service, U. S. Department of Agriculture, Washington, D. C.

out of the grower's control. Although the cost of raising a crop is largely fixed, the cost of producing a pound of mushrooms often varies considerably from one crop to another, depending on the yield per square foot of bed space. The price differs from one locality to another and from one season to another.

Warm spells in the early fall and late spring may greatly increase the supply of mushrooms for several days at a time by raising the temperature in mushroom houses. The temperature rise is reflected in an increased rate of growth of the mushrooms and in the production of a larger proportion of buttons. In congested centers of mushroom growing this usually occurs in hundreds of mushroom houses at the same time, and the grower often finds himself in the untenable position of producing the most mushrooms when the price is below the cost of production.

If an average crop is attained and the total cost of production is assumed to be 15 cents a pound, the costs would be divided approximately as follows: Interest on investment, depreciation and upkeep of buildings, 2 cents; raw materials, 7 cents; and labor, 6 cents. The estimated cost of manure may differ as much as 3 or 4 cents from one locality to another; the interest and depreciation charge may be reduced when abandoned buildings or caves are used; and labor cost will vary in different localities and in different years. Otherwise costs are fairly comparable in different localities. In some localities spent manure or "mushroom soil" is sold to truck gardeners, but this rarely returns an income of more than enough to pay for hauling it away.

Except in isolated cities where one or two growers control the supply, mushrooms are sold on consignment, and the price received for them is based on the prevailing values, as indicated by sales from receivers and wholesalers or retailers. In New York and Chicago the receiver charges a commission of 10 percent for handling mushrooms. The white variety commands a better price than the cream or brown, and large mushrooms bring a higher price than buttons. Canners specialize in high-quality button mushrooms and often fix a purchasing price in the fall that remains fairly constant throughout the winter.

Prices have been receding during the past 10 years. On the New York market a price of 55 cents per 3-pound basket is perhaps a little higher than the average paid to the producer. In some of the western markets 5 or 10 cents a pound more is received.

DRYING MUSHROOMS

The dried mushrooms sold in the United States are imported largely from Europe and the Orient. As a rule these mushrooms are not of the species cultivated in this country. In Europe they are gathered wild, and in the Orient they are grown on logs or on rice-straw beds. Several attempts have been made by large mushroom growers in America to introduce the common cultivated variety into the market in a dried or powdered form. For various reasons, such as extreme shrinkage in weight during drying and competition with a fresh or canned product of similar kind, the drying of mushrooms has not been found profitable in this country.

Mushrooms can be successfully dried by being placed on wire trays, one layer deep, and having a rapid current of warm dry air passed over them. If the temperature of the mushrooms is raised to 130° F. for a few hours during drying all insects infesting the mushrooms will

be killed. When thoroughly dry and maintained free from insects, mushrooms will keep in good condition for several years and retain most of their original flavor. Dried mushrooms, like other dried vegetables, are subject to rapid decay and spoilage if exposed to moisture or high humidity.

MUSHROOM DISEASES

There are three general classes of mushroom diseases: Those caused by parasitic fungi or bacteria; those caused by fungi that make conditions unfavorable for the mushroom by growing like weeds in the bed; and those that cause malformation of the mushroom apparently stimulated by nonliving irritants. The bubbles and brown spot diseases are examples of the parasitic type, and rose comb is an example of the irritant type.

BUBBLES

Bubbles is the most destructive disease of cultivated mushrooms. It is caused by the fungus *Mycogone perniciosa* Magn., which grows in the mushroom and transforms it into a distorted, putrid mass. Soon after the mushroom is attacked, the parasite produces a layer of white or brown spores over the surface. These spores may be spread by various agencies and are able to live through a long rest period under unfavorable conditions. The recurrence or accumulation of the disease from one crop to another indicates that the fungus either is remaining alive inside the house from one crop to another or is being carried into the house during one of the cultural operations. There are several possible methods of introducing the fungus into the house, in the air or on insects entering through doors or ventilators, in the water, spawn, compost, or soil, or on the clothing or hands of workmen.

If the house is thoroughly disinfected with either sulfur or formaldehyde there is practically no chance for inoculum to remain in the house from one crop to another. Likewise, disinfection of the area surrounding the house and sanitary disposal of mushroom refuse will materially reduce the danger from wind-blown or insect-carried spores. If an open well is used, it may be necessary to disinfect it occassionally. There is little chance for *Mycogone* to be spread in bottle spawn that has been made under aseptic conditions.

Mycogone is killed by long exposure to moderately high temperatures. All the evidence at hand indicates that a temperature of 120° F. for 48 hours in a mushroom house will eradicate the fungus from the house. Therefore the manure in a house that has been through a good heat should be free from *Mycogone*. This and other circumstantial evidence indicates that most severe outbreaks of bubbles in commercial houses are due to carelessness in disinfecting the house or to infested casing soil.

Losses from infested casing soil can be eliminated by taking precautions to prevent the contamination of the soil. To determine whether soil is contaminated, small test beds may be cased with soil samples taken from fields that are to be used as sources of soil for subsequent crops. If soil infestation becomes general and there is no *Mycogone*-free soil available, the fungus can be eradicated by heating the soil to at least 120° F. for 48 hours. This can be done in specially equipped rooms or by placing the soil in trays or ½-bushel baskets near the top of the house during the heat. When the soil is heated

to more than 150° F., *Mycogone* spores are killed in less than an hour. Some growers find partial sterilization with live steam, as described in Farmers' Bulletin 1629,[2] very satisfactory. Others complain of a loss of water-holding capacity and molding of the steamed soil. The injurious effect of steaming apparently varies with different types of soil and in many cases is temporary and can be eliminated by steaming several weeks before the soil will be needed for casing or by aeration of the steamed soil.

After the disease has become established in a house, strict sanitary measures are necessary to prevent workmen from spreading it. The loss may be reduced somewhat by growing the crop around 50°.

The measures outlined above apply particularly to the prevention of the disease in conventional mushroom houses, but the principles may be applied to most situations.

VERTICILLIUM DISEASE

Verticillium disease, also known as the brown spot disease, is caused by the fungus *Verticillium malthouser* Ware, and is evident in most commercial mushroom houses toward the end of the crop. The most characteristic symptom of the disease is the presence of brown blotches on the mushroom caps, with a bluish-gray mold barely visible after the spot is a few days old. In severe cases the disease may resemble bubbles, but usually the deformation is accompanied by cracking of the mushroom stem and cap due apparently to the retarding of growth of the mushroom in the parts infected with the brown spot fungus.

The spores of the fungus causing this disease are killed by pasteurizing temperatures, so that most of the inoculum responsible for the early appearance of the disease probably comes into the house in the soil. The disease spreads very rapidly once it is established in the house, and it is practically impossible to check it by disinfecting early centers of infection, as is frequently recommended for the *Mycogone* fungus.

Once the disease makes its appearance, the most practical methods of control are taking off the crop at a temperature below 55° F. and adopting special precautions during watering. The spots on the surface of the mushrooms represent centers of infection caused by the germination and growth of *Verticillium* spores. These spores require for germination 4 or 5 hours either in a relative humidity of over 90 percent or in a droplet of water. Thus a system of watering that will avoid high humidity and reduce the time that water is present on the mushrooms tends to check the spread of the disease. This is usually accomplished by ventilating or raising the air temperature during watering, so as to cause rapid evaporation of the water unavoidably spattered on the mushrooms.

Spraying with bordeaux mixture 1–1–50 has been shown to partially control this disease and may be advisable as a control measure where the disease has progressed beyond the possibility of control by regulation of temperature and watering.

TRUFFLE DISEASE

The truffle disease caused by the fungus *Pseudobalsamia microspora* Diehl and Lambert, although sporadic in its appearance, is frequently responsible for more than a 25-percent loss in the crops of individual

[2] JOHNSON, JAMES. STEAM STERILIZATION OF SOIL FOR TOBACCO AND OTHER CROPS. U. S. Dept. Agr. Farmers' Bull. 1629, 14 pp., illus. 1930.

growers. It is characterized by the development of cream-colored wefts of fungus mycelium, which appear under the side boards and in the manure at about the time of casing. The truffles fungus seems to stimulate rather than prevent the run of spawn in the early stages of the crop. A few weeks later, however, when the fungus matures and forms wrinkled fungus bodies in the manure and on the soil, the infested parts of the beds become barren, and the mushroom mycelium almost completely disappears.

The source of this fungus is not known, because it has not yet been found outside of mushroom houses. However, the nature of the fungus and the history of the disease suggest that the fungus lives in the soil and is carried into the house in the compost. There is also some evidence that it may remain from one crop to another in the bed boards and that early fall crops accompanied by high temperatures, an overwet condition of the manure, and storing manure all tend to favor its development. The spores are probably distributed principally at the time of emptying the beds.

It would seem advisable, if a house has been infested with truffles disease, to take the following precautions: Thoroughly fumigate the empty mushroom house with formaldehyde gas; disinfect the compost grounds by drenching them with a solution of formaldehyde (1 quart of formalin to 15 gallons of water) or change the composting grounds; do not add soil to the manure or, if soil is added, change the source from which it is obtained; wet down the spent mushroom soil at the time of emptying to prevent the spread of spore dust; disinfect the truck used to haul spent soil; avoid storing manure, growing early fall crops, running the spawn at high temperatures, and letting the compost become wet and soggy during fermentation in the pile or in the house. In some cases soaking bed boards in disinfectant seems to have been beneficial. However, until more is known about the source of the infestation and the conditions that favor infestation, all control measures must be considered tentative, and no control program can be offered that will assure the eradication of the disease.

OTHER DISEASES

The olive mold disease is caused by another weed mold in the compost, *Chaetomium* spp. The spores of this mold are present in nearly all compost. If conditions are favorable, it will grow throughout the beds and tend to crowd out the mushroom mycelium. It is recognized by the profuse development in the compost of olive-colored tufts about the size of buckshot. The olive mold fungus is only abundant in undercomposted manure or in manure that has been overheated (more than 145° F.) without subsequent reconditioning for a few days between 130° and 140° F. Compost that has been properly sweated out cannot be invaded by the olive mold even though spores of the mold are present in the manure.

There are four types of fleshy fungi that sometimes appear on beds of cultivated mushrooms, *Coprinus* spp., *Panaeolus* spp., *Pleurotus* spp., and *Peziza* spp. These weed fungi are an indication of under-composting or excessive watering of the manure. Certain species of *Panaeolus*, if eaten in quantity, will cause poisoning, acute indigestion, and vomiting, but it is almost inconceivable that anyone who has seen cultivated mushrooms could confuse them with *Panaeolus* (fig. 18).

The presence on the bed of a large proportion of deformed mushrooms with superfluous gills over the upper surface of the cap resembling the rose comb of poultry and sometimes deeply seamed and cracked has been traced in many cases to mineral oil or oil products. In some cases abnormalities were apparently due to the use of kerosene in smudges, disinfectants, and insect sprays. In others they were due to accidental contamination of the water supply with oil or grease.

FIGURE 18.—*Panaeolus* sp., a fungus weed that sometimes develops on beds of cultivated mushrooms.

There are several other minor diseases and weed molds. For a detailed discussion of all mushroom diseases the reader should refer to Pennsylvania State College Bulletin 351.

INSECTS AND OTHER PESTS [3]

The principal pests causing damage in commercial mushroom houses in the United States are mushroom flies (Sciaridae), manure flies (Phoridae), the mushroom mite, the long-legged mite, and several species of springtails. In addition to these there are a number of pests of lesser importance.

Extensive experiments have demonstrated that the control of mushroom insects and mites, once they have become established in the houses, is very difficult, owing to the extreme sensitiveness of the mushrooms to chemicals and because the chemicals that have so far been in use and are known to be safe to use do not readily penetrate into the beds. Nevertheless, by means of sanitation, proper com-

[3] By A. C. Davis, assistant entomologist, Bureau of Entomology and Plant Quarantine, U. S. Dept. of Agriculture. More detailed information upon mushroom pests and their control will be found in U. S. Department of Agriculture Circular No. 457, Mushroom Pests and Their Control, which is out of print but is available in most libraries.

posting and heating, and fumigation, these pests can be reduced in numbers or entirely eliminated before the beds are spawned and largely prevented from entering the houses thereafter.

The proportion of manure in a compost pile in which mites and insects can survive is relatively small. By properly preparing and disinfecting the composting floor many insects are prevented from entering the manure, and by proper turning of the manure most of those that do become established are killed during composting.

If the mushroom house is properly prepared before being filled, that is, if it is sprayed with boiled lime-sulfur or some other disinfectant, of which there are several available, or fumigated with either formaldehyde or sulfur, there will be very few if any insect or mite pests left in it.

The house should be filled as quickly as possible and closed tightly so that as little as possible of the heat of secondary fermentation will be lost. As the beds heat, insect and other related pests will be either killed by the heat or driven from the inside of the compost to places where they may be reached by fumigants. Temperatures above 120° F. in the beds are desirable for this purpose. Artificial heat is sometimes necessary to raise and maintain the temperature at or above this point. Fans should be used, preferably with the blast directed downward from the top of the house, to distribute the temperature more evenly.

If the temperature upon the floor of the mushroom house could be raised to 120° F. or higher, it probably would destroy all pests, thus eliminating the necessity of fumigating the house. Unfortunately this is not possible in most mushroom houses, so it is desirable to fumigate when the house is at peak heat. For this purpose flowers of sulfur, at the rate of 2 pounds per 1,000 cubic feet of air space (exclusive of the space taken by the beds), or hydrocyanic acid gas should be used. Owing to the slow rate of burning and the rapid absorption of gas by the moisture in the house, it is doubtful whether an efficient fumigation is ever attained by burning sulfur in pans within the house at peak heat. An apparatus for burning the sulfur outside the house and blowing the fumes in has been developed and gives much better results. Details of the construction and use of this burner are given in United States Department of Agriculture Circular 457, which is out of print, but may be consulted in libraries.

When a house to be fumigated is immediately adjacent to another in production, every precaution should be taken that the fumes do not reach and damage the growing mushrooms. The ventilators of the house in bearing should be open, and the house in heat should be fumigated only when there is no wind or when the wind is blowing away from the house in bearing. In case of a double house, the other half of which is in bearing or spawned, it is better to fumigate with hydrocyanic acid gas than to risk damage from sulfur fumes.

FUMIGATION OF MUSHROOM HOUSES WITH HYDROCYANIC ACID GAS

The two materials in common use for hydrocyanic acid gas fumigation are (1) calcium cyanide and (2) sodium cyanide and sulfuric acid.

Hydrocyanic acid gas is deadly poison, and extra precaution must be taken when using it. A gas mask should be worn while scattering the cyanide and always when entering a house after fumigation.

The mask should be carefully inspected for leaks each time it is used. Instructions on care and use of gas masks can be obtained by writing the U. S. Department of Agriculture.

Calcium cyanide and sodium cyanide should only be purchased in quantities sufficient for immediate use, so that they will not have to be stored and thus be accessible to children or careless adults.

Calcium cyanide is at present the material in most common use for fumigating mushroom houses. It is used at the rate of 1 pound per 1,000 cubic feet of air space. As hydrocyanic acid gas is readily absorbed by moisture, the house, although damp, should not be wet, with puddles of water standing in the alleyways, or much of the gas will be lost before it is fairly liberated. Experiments have shown that the maximum concentration of gas is reached in from 10 to 20 minutes after calcium cyanide is scattered.

In view of the deadly nature and the rapid evolution of hydrocyanic acid gas, every precaution should be taken against accidents. In the case of a single house, the chemical should be scattered in the central alleyway as evenly and quickly as possible, beginning at the back of the house and working toward the door. Special care should be taken to have the alleyway clear of obstructions before the fumigation is begun, as the results might easily prove fatal to an operator who stumbled over some obstacle while walking backward and scattering the cyanide. In the case of a double house the material is scattered in the two main alleyways, the workers starting together at the far end and working toward the doors, timing themselves so as to reach the doors simultaneously. After the operators have left the house the doors should be closed and tightly sealed and left so for about 12 hours.

Caution: When entering a house after fumigation, use a gas mask until the house has been thoroughly aired out.

The so-called pot method of fumigation, in which sodium cyanide and sulfuric acid are used, is almost as easy and convenient as that with calcium cyanide and gives a more rapid liberation of gas and a much higher concentration. The material should be used at the rate of not less than 8 ounces of sodium cyanide to 12 fluid ounces of a good grade (66° B.) of commercial sulfuric acid and 16 fluid ounces of water per 1,000 cubic feet of air space. Three or four 3-gallon glazed crocks may be used for generators. The necessary quantity of water is measured out and divided among these. They are then set at equal intervals in the central alleyway of the house. The acid is similarly measured out, and the necessary quantity placed in a glass jar beside each generator. The sodium cyanide having been similarly weighed out (it can be obtained in ½-ounce or 1-ounce "eggs" to save this work) and the proper quantity for each jar having been put into a heavy brown paper bag (the thickness of paper may be doubled for additional safety by using two bags, one inside the other, for each charge), the operator takes the twisted necks of the bags in his left hand, enters the house, and pours the acid into each generator as he reaches it. Having reached the back of the house, he walks rapidly toward the door, placing one bag of cyanide in each generator as he passes it. The acid requires a short time to eat through the paper bags, and the operator is usually well outside the door before the first charge begins to generate gas.

Sodium cyanide is extremely poisonous, and great care should be exercised in handling it. It should be stored under lock and key

where it is not accessible to children or careless persons. The same precautionary measures should be taken with the acid.

The same rules as to procedure and safety apply to fumigation at peak heat in cellars or other small spaces as apply during preparation for the crop. **Hydrocyanic acid gas should not be used in or adjacent to dwellings at all, and sulfur only when there is no possibility of the fumes escaping.** In these places it is better to depend upon heat for mushroom-pest control at any time when the beds do not contain spawn.

SANITARY MEASURES

After the house has been through the "heat" and has been properly fumigated, precaution should be taken to prevent reinfestation by insects and the other closely related pests mentioned previously. Doors and ventilators may be made fly-tight with cheesecloth, or, better, 30-mesh copper screen, if it is found possible to do so without interfering too much with ventilation. This prevents the entrance of flies and also of any mushroom mites that they may be carrying.

All stem butts and discarded mushrooms should be carried away and burned, or placed in a hole and then covered with quicklime or kerosene and a layer of earth. They should never be allowed to stand about the house.

When the house has finished bearing and is about to be cleaned out, it should be allowed to dry out thoroughly and be fumigated if possible. In any case, the spent compost should be hauled to some distance from the houses and spread out thinly over the soil so that the weather may destroy as many of the pests as possible.

After the beds have been cased, the temperature should be kept rather low. For the best results it should be possible to maintain an air temperature ranging from 50° to 55° F. A temperature below 55° F. is more to be desired than one above that level, as the lower temperature seems to be favorable for mushroom growth and is low enough to retard materially the development of insect and other pests of mushrooms.

PRINCIPAL PESTS AND THEIR CONTROL

Sciarid flies of the genus *Sciara*, known as mushroom flies or fungus gnats, and phorid flies of the genus *Megaselia*, known as manure flies, are, on the whole, probably the most important mushroom pests. The adult flies are known to carry mushroom mites and to spread certain mushroom diseases, and the larvae, or maggots, attack the spawn and sometimes even destroy mushrooms upon the beds.

The sciarid flies (*Sciara* spp.) are black to yellowish, of slender build, with long legs and antennae. The eggs, in numbers ranging from 200 to 300 or more, are laid in the compost or spawn and in cracks in the casing soil. The maggots are legless, with black heads, and complete their development into the adult fly in from 19 days to a month or more, depending upon the temperature.

The phorid flies (*Megaselia* spp.) are black or blackish and usually smaller than the sciarid flies. They are much more compactly built, the legs are stouter and not so long, and the head is rather small and the thorax large, giving them a humpbacked appearance. They are active, moving about constantly in a series of jerky runs. The eggs are very minute, white, and elongate-oval and are laid in the compost

or casing soil. They hatch in about 6 days, under usual mushroom-house conditions. The larvae, or maggots, are shining white or yellowish, about one-fourth inch long when fully matured, legless, and without head capsules. After feeding for 10 days or more, the maggots stop feeding and transform into yellowish pupae, appearing almost like small seeds. From these, after another interval, the adult flies emerge.

No effective method has yet been devised for controlling the maggots of mushroom flies or manure flies within the beds. Control must be had through reducing the number of adult flies, thus decreasing the number of eggs laid. Traps and insecticides are the principal means of killing the adult flies. Traps are of several varieties, but all depend upon light to attract the flies. The simplest type is a pane of glass set into the end of the house, with sticky flypaper or a pan containing a little kerosene placed under it to catch the flies that come to the light. The pane of glass should have an area of about 72 square inches. Insecticidal dusts are of several types, but all consist mainly of pyrethrum plus some kind of carrier.

The house should be watched carefully, and as soon as a few flies appear, it should be treated with the dust at the rate of 2 or 3 ounces per 1,000 cubic feet of air space. Most growers dust two or three times a week. Before dust is applied, the temperature of the house should be allowed to reach 60° F. or more; then the dust should be applied and the house should be left closed overnight. At any lower temperature the flies are less active and the dust more inert. A good fan-type duster should be used and the dust thoroughly distributed throughout the house. If a duster is not available, a good distribution of the dust may be obtained by shaking the dust slowly out of a bag into the air blast from an ordinary electric fan directed toward the ceiling of the house.

Fumigation with calcium cyanide at the rate of 2 ounces per 1,000 cubic feet of air space has been recommended for controlling mushroom flies and manure flies, but some damage has been reported from its use.

Gall gnats are small, delicate, brownish flies with orange abdomens. They are seldom seen. The larvae, or maggots, are white to orange and are about one-eighth of an inch long. At times they congregate in enormous numbers upon the mushrooms and casing soil. Control of the adults by dusting and of the larvae by drying out the beds or by drenching the beds with hot water has been reasonably successful.

Mites of several species occur less commonly than the flies but are capable of causing great damage to the crop in mushroom beds. They attack both the mycelium in the beds and the growing and mature mushrooms. Once they have become established in a house, they are difficult to control. Prevention is the best means of combating them. It is important that the house go through a good heat so that as many as possible of these pests will be killed.

Springtails of a number of species cause damage in mushroom beds by feeding upon the mycelium and making pits in the mushrooms. They are usually gray or blackish. Beneath the abdomen of each insect there is a powerful springlike appendage which, when released, is capable of hurling the insect through the air for a distance many times its own length. Some species have a habit of congregating in enormous numbers, appearing as piles of gray powder in the aisles.

When found in this condition, they should be swept up and burned or dusted with 3-percent nicotine-lime dust. If the beds are watered, the springtails may be brought to the surface within 3 to 4 hours and then dusted.

Sowbugs, slugs, and crickets are best controlled by hand-picking them off the beds.

NEW DEVELOPMENTS

INCREASE IN AVERAGE YIELD

During the past 10 years the average commercial yield of mushrooms has increased from approximately 1 pound per square foot of bed space to about 1½ pounds. This 50-percent increase does not seem to be traceable to any one particular factor but rather to a better understanding of the numerous essential features of mushroom growing. The following are some of the factors at least partially responsible: A realization of the harmful effects of overheating during sweating-out, the use of fans for vertical circulation of air during sweating-out, the use of the pH value as an indication of the proper duration of sweating-out, control of bubbles through the selection and treating of casing soil, control of the pH value of casing soil, recognition of conditions conducive to the truffles disease, improvements in fumigation and insect control, and the selection and improvement of spawn strains.

USING LESS MANURE

Another noticeable change in commercial practice during the past decade is the tendency toward the use of less and less manure per square foot of bed space. In 1930 the average grower was making up about 70 square feet of beds from a ton of manure. At the present time it is a common practice to make up between 80 and 100 square feet per ton. In some cases growers are obtaining an additional one-half to three-fourths pound of mushrooms per square foot by turning the spent beds upside down and recasing.

TWO-ZONE OR TRAY SYSTEM

The tray system, or two-zone system, of cultivating mushrooms is a new development that is particularly well adapted to growing mushrooms in caves or abandoned factories. The essential features of this system are the placing of compost in moveable trays instead of beds so as to make it possible to sweat out in an especially adapted room for this purpose and then growing the mycelium and mushrooms in a cave or abandoned building.

SYNTHETIC COMPOST

This product, which has already been discussed in some detail (p. 11), is also a development of the past decade.

SPAWN MAKING

Interesting innovations in the production of pure culture spawn have been developed in recent years. One of these is the use of a truncated cone-shaped glass spawn container with a removable

cover, which makes it convenient to empty the spawn from the glass jar. Another is the use of various sterilized materials to supplant washed horse-manure compost as a spawn medium. Various kinds of grain, tobacco stems, and a bran-soil mixture have been used successfully.

AMATEUR MUSHROOM CULTURE

The amateur grower operating on a small scale can follow many of the methods of the commercial grower, but he usually is unable to assemble large compost heaps, to sweat out or pasteurize the manure, or to adequately fumigate the premises. As a consequence he must be content with an average yield of three-fourths of a pound per square foot of bed space, whereas the commercial grower, operating on a large scale, with special facilities, obtains an average yield of 1½ pounds per square foot. The principal requirements for cultivating mushrooms and the compromises that can be made by the

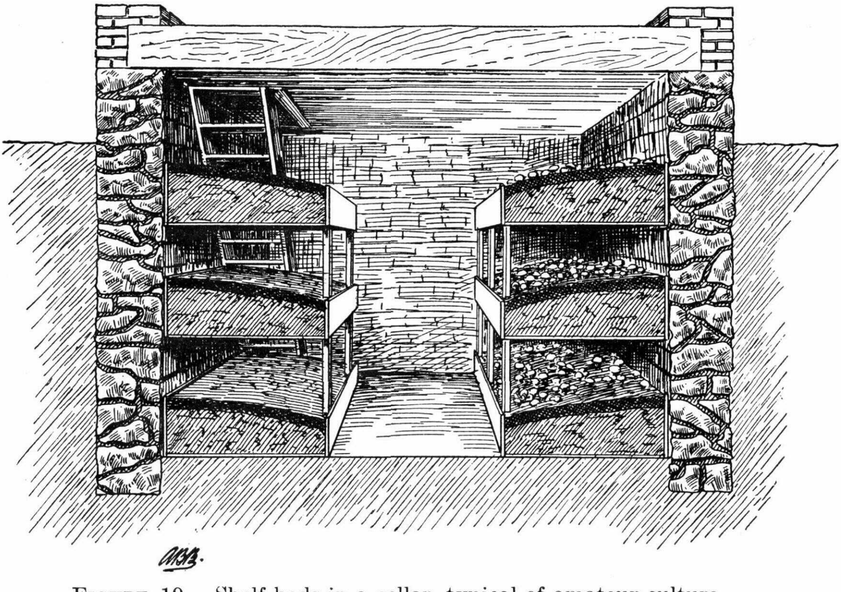


FIGURE 19.—Shelf beds in a cellar, typical of amateur culture.

amateur without too seriously reducing the chances of a crop are discussed briefly in the following paragraphs.

The prospective grower must have available (1) vigorous spawn, (2) horse manure or an equivalent synthetic compost for making the beds, (3) neutral loam soil for covering the beds, and (4) growing rooms where cool temperatures with moderately high humidity can be maintained.

The first requirement can be met as easily by the amateur as the commercial grower. It is simply necessary to purchase good, vigorous spawn.

As a rule the amateur grower can, with a little persistence, find a suitable source of horse manure, but he is handicapped in that his small heap will not compost as well as the large heap of the commercial

grower. This is because of the excessive aeration to which small compost heaps are subject. To reduce this, the amateur should shake out much of the straw from the manure and mix neutral soil with it half-and-half by weight. Manure prepared in this way can be composted in ½-ton or 1-ton piles. Under these circumstances it does not heat as well as in larger piles but decomposes about as rapidly. The same criteria of a finished compost should be followed with the small heap as with the large one. If the manure has a tendency to become wet and sticky, add 1 percent by weight of superphosphate, or of gypsum to the pile.

In most instances the amateur will find it necessary to forego the pasteurizing or sweating-out process in the beds. On an average this will result in reduced yields, and crops of less than 1 pound per square foot may be expected. Thorough spraying of the empty beds with calcium hyperchloride is advised between crops to prevent the accumulation of pests carried in with the manure. Boiled lime-sulfur would be better, but it leaves an objectionable odor.

The control of temperature for spawn run, the application of casing soil, watering the beds, picking, etc., can be carried out fully as well by the amateur as by the commercial grower. If a cellar room is used as a growing room it should be partitioned off from the remainder of the cellar in order to make it possible to maintain a cool temperature and high humidity. Beds can be made up on the floor or in shelves, whichever is most convenient (fig. 19). The space under the cellar stairs is frequently used.

U. S. GOVERNMENT PRINTING OFFICE: 1941